First Draft Plan: Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability

BACKGROUND

In 2008, the US Fish and Wildlife Service (Service) issued a Biological Opinion (BiOp) on Central Valley Project (CVP)/State Water Project (SWP) operations that concluded that aspects of those operations jeopardize the continued existence of delta smelt and adversely modify delta smelt critical habitat. Among other requirements, the Reasonable and Prudent Alternative (RPA) that was issued with the BiOp calls for the adaptive management of fall Delta outflow (hereafter "Fall outflow") in certain water-year types. The Service determined that the Fall outflow element of the RPA is required to alleviate both jeopardy to delta smelt and adverse modification of delta smelt critical habitat. The Fall outflow action is expected to improve habitat suitability and contribute to a higher average population growth rate of delta smelt.

The RPA prescription is expressed in terms of X2, the nominal location of the 2 ppt isohaline (Jassby et al. 1995). The RPA calls for Delta outflow to be managed such that fall X2 must average either 74 km or 81 km upstream from the Golden Gate during each of September and October, respectively, if the water year containing the preceding spring was classified as wet or above normal. There is an additional storage-related requirement to enhance outflow in November that does not have a specific X2 target. The RPA states that the performance of the action shall be investigated with a research and monitoring program containing a feedback loop allowing it to be adjusted from learned information (i.e., adaptive management).

At the time the BiOp was issued, the Bureau of Reclamation (Reclamation) responded with a "provisional acceptance" letter. In 2009-10, Reclamation and the Service developed and initiated a package of studies designed to increase understanding about Fall X2 and support future decisions regarding it.

With this document, Reclamation has sketched a "first draft" active adaptive management plan. Reclamation hopes to formulate a scientifically supported plan that satisfies its needs and avoids jeopardy and adverse modification of delta smelt critical habitat.

This document includes a draft statement of management goals, a description of how adaptive management works and how manipulative experimentation can responsibly be incorporated into it, and an initial draft of the essential plan elements. Since a starting point for the management is logically required, a discussion of the management alternatives and initial action is also presented. Since it is not yet known whether an action would be called for in 2011 under the triggering rule currently articulated in the RPA, this discussion is not specific to 2011.

This draft plan implements a critical recommendation made by the National Academies of Science panel in its March 2010 report (available at http://www.nap.edu/catalog.php?record_id=12881). By completing the foundation for rigorous, science-based adaptive management, it will enable the effective management of Fall outflow and increase our understanding of the interrelationships among Fall outflow, ecosystem dynamics, and delta smelt abundance and distribution.

Two important points must be emphasized. First, this is not a decision document, and nothing in this document should be construed as representing or anticipating a decision by either Reclamation or the Service as to what initial operations would be appropriate in an adaptive management plan. Second, this is a draft staff analysis that considers a possible framework for responding to the scientific and operational challenge presented by Fall outflow management. It is intended to stimulate technical discussion and to invite technical advice from stakeholders on the scientific aspects of adaptive Fall outflow management. The document is not, however, a finished product, and it may contain the sorts of errors, omissions, or inadvertent misstatements that often occur in drafts.

After a stakeholder workshop on May 11-12, 2011 to discuss the scientific challenges of Fall outflow adaptive management, Reclamation will coordinate with DWR to complete a Fall outflow adaptive management plan for review by the Service. For the initial science component of its plan, Reclamation will use material drawn from this draft document, various sources of outside technical advice, and publicly available scientific information. Reclamation will fully consider water supply implications and possible management conflicts with Shasta cold-water storage (an issue for winter-run Chinook salmon management), and both CVP/SWP operations managers and the NOAA Fisheries Service will be consulted during the completion of the plan. In addition to review by the Service for its adequacy in meeting ESA requirements, the plan will also be subjected to review by a Delta Science Program-appointed panel of independent experts before an implementation decision is made.

BASIC ADAPTIVE FRAMEWORK

Adaptive management is a mode of management that provides for structured learning and feedback to adjust an action undertaken in the face of uncertainty. The draft plan follows the Department of Interior (DOI) Technical Guide (http://www.doi.gov/initiatives/AdaptiveManagement/) fairly closely. The DOI Guide defines the general adaptive management approach as a looped process of six steps.

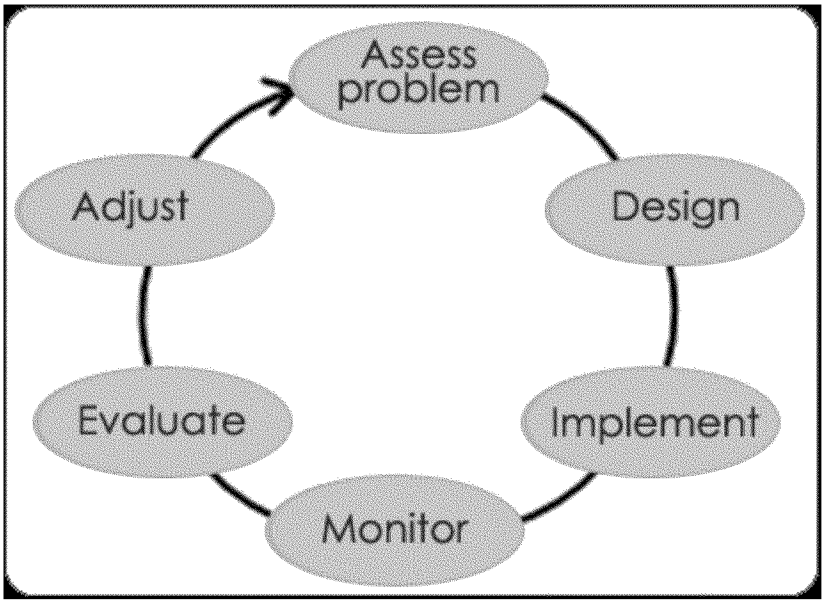

Figure 1. Adaptive management cycle (reproduced from DOI Adaptive Management Technical Guide).

The loop is initially entered at the "assess problem" step, which includes setting overall goals. For Fall outflow, we expect that the basic feedback loop would be closed annually. This implies that field and possibly laboratory data would be collected annually, regardless of water-year type and whether Fall outflow were augmented. After each year's experience, a workshop and expert panel review would be used to explore what had been learned to date and what adjustments to the action and investigation should be considered.

While the steps in this loop are intuitively obvious, implementing a workable system to achieve learning can be a major challenge. In particular, the key to successfully navigating the sequence DESIGN → IMPLEMENT → MONITOR → EVALUATE lies in establishing management objectives that have the following features. Objectives must be:

1. Specific and unambiguous, with clear metrics and target conditions;
2. Measurable, with elements that can be readily observed, to promote evaluation of the management action;
3. Achievable, and based on the capabilities of the physical, political, and social system within which management occurs;
4. Results-oriented, with resource end-points and/or conditions, such as habitat conditions, representing their achievement;
5. Time-fixed, such that resolving the outcome of management choices occurs within an expected time-frame.

Defining objectives that satisfy all of these conditions is difficult in most real-world adaptive management situations. It is clearly difficult here. One of the hardest problems raised by consideration of Fall outflow management lies in defining a satisfactory population-level delta smelt objective that can be reliably measured. This is a consequence of the species' catastrophic decline in abundance. Because delta smelt are rare, we cannot expect to detect an abundance difference after a single year of flow augmentation by means of the standard trawl surveys unless the abundance difference is very large. Other biologically important differences might not be detectable without many observations. To help overcome this difficulty, it is necessary to consider using every investigational tool that can responsibly be applied, including careful outflow experimentation.

The term 'active adaptive management' (e.g. Walters 1986) has been used to describe the use of experimental manipulation embedded in management action as a learning tool. Experimental manipulation of Fall outflow offers a better chance to learn about population level Fall outflow effects. Given the potentially high water costs of implementing Fall outflow actions and concomitant need to learn about the effectiveness of high-outflow management alternatives as quickly as possible, the active approach is strongly to be preferred and its use is a premise of this exercise.

The draft plan, outlined below, focuses more on the PROBLEM → DESIGN → IMPLEMENT → MONITOR → EVALUATE arc of the adaptive management cycle than on the ADJUST step. The adjustment step is more complex than it may appear, since it logically includes not only adjustment of the basic management action but also adjustment of the management alternatives that are carried forward, and potentially adjustment of the problem statement itself.

Reclamation invites technical advice on all aspects of Fall outflow adaptive management, including the means by which the agencies might develop management decisions. This document is intended to encourage discussion and advice on the content of a Fall outflow plan, including raising competing hypotheses to be investigated. Feedback on the use of adaptive management itself is also welcome.

ROLE OF STAKEHOLDERS

It is a tenet of adaptive management that stakeholder involvement is essential to success. For that reason, the development process is intended to be open and transparent. Technical assistance in developing an effective process to reduce uncertainty with respect to Fall outflow and its effects on delta smelt, including establishing the scope, objectives, and means by which questions about the effectiveness of management strategies will be resolved, is invited.

Elements of a First Draft Plan

The preceding discussion established the background for Fall outflow management, the basic active adaptive management framework that the draft plan is based on, and the essential role of stakeholder participation in developing a technically strong plan.

The remainder of this document lays out draft plan elements that observe the conventions of adaptive management as described in the DOI Guide. Together, they provide "first draft" components for an adaptive management plan, discuss initial experimental alternatives, and establish a means of evaluating outcomes that is based on monitoring and quantitative statistical models. The approach does not address the ADJUSTMENT step in Figure 1 in great detail, but follows Walters (1986) and others in assuming that management decision-making is based on assessment of the relative performance of competing models in the face of experience with contrasting management alternatives.

The conceptual model developed in the draft plan follows the analysis in Feyrer and others (2007, 2010) in positing that variation in outflow drives changes in abiotic delta smelt habitat quality and quantity (HQQ), which in turn causes biological effects, including some that may alter the vital rates of delta smelt.

The plan also discusses a different and (apparently) largely non-intersecting conceptual model developed by Glibert (2010) that relates plankton dynamics to nutrient concentrations that are potentially subject to manipulation by variation in outflow. Although the Glibert model says nothing about abiotic smelt habitat, it provides an example of how other conceptual models might be investigated in tandem with the HQQ model.

If stakeholders are aware of other conceptual models relating fall outflow to delta smelt vital rates or other relevant variables, we hope they will contribute to this process by casting those models in a form that can be modeled and reduced to specific predictions about the outcome of different management choices.

It is desirable that species-specific full life cycle models be developed that integrate actions like Fall outflow. However, it is important to recognize that the level of quality and mechanistic detail required for a life cycle model to be useful in this application is high. At present, the delta smelt life cycle models we are aware of are either not spatially explicit or not sufficiently detailed to address Fall outflow effects. The development of improved mechanistic models and, perhaps, realize new applications of life cycle models in adaptive management, will be a fruitful topic for discussion. Stakeholder advice is solicited.

DRAFT ELEMENT: GOALS

The goals addressed by this plan are (1) to manage Fall outflow for conservation benefits to delta smelt while minimizing water supply and water supply reliability impacts; (2) to increase understanding about the effectiveness of Fall outflow for smelt conservation about how to structure the action.

DRAFT ELEMENT: PRIORITY HYPOTHESES

1. Moving X2 downstream in the fall relative to previous years will result in an increase in the quantity and quality of habitat for juvenile delta smelt, which will translate into more growth and less mortality caused by increased opportunities to encounter high-density food and turbid areas, including food production originating in Suisun Marsh. These changes will result in greater average recruitment in the year following the action.

2. Fall outflow augmentation will slightly reduce the concentration of ammonium, weakly affecting primary productivity via wastewater trophic forcing (Glibert 2010), but will not affect the N:P ratio. The nutrient changes that do occur will not affect plankton numbers or distribution, and will not alter opportunities for delta smelt to encounter high-density food and turbid areas.

DRAFT ELEMENT: INITIAL MANAGEMENT ACTION AND ALTERNATIVES

The starting point for this plan includes the initial conservation action and the initial set of potential management alternatives built around it. The starting point depends on two main considerations. The first is that the management approach, including the manner in which the alternatives are deployed for study, must provide necessary conservation benefits to delta smelt. The second is that the management alternatives and the approach to deploying them must provide opportunities for learning. Both considerations limit the universe of possibilities.

Since this is a "first draft" plan that is meant to solicit technical advice, it relies on the analysis provided in the 2008 BiOp that concluded that the outflow augmentation action prescribed in the RPA is required to alleviate jeopardy and adverse modification of delta smelt critical habitat. Hence, the initial conservation action is to meet the targets identified in the 2008 RPA.

With respect to the initial choice of management alternatives for learning, a review of the Fall outflow record reveals that during the past decade Fall outflow in wet and above normal water-years has been stable and roughly equal to what was previously observed only in drought years. To the extent the effects of low Fall outflow in the recent past have been measured by the IEP long-term monitoring program and other activities, we can study the effects of variation in Fall outflow on the basis of the historical data and various kinds of modeling. Biological models fitted to low-outflow data could be used to forecast how those variables might behave if higher outflow were imposed. However, since the domain of those predictions lies outside the realm of recent historic experience, there would be substantial risk in relying solely on such models to develop a management strategy That is particularly true in this case because of the long history of progressive ecosystem change and the conclusion of some Pelagic Organism Decline (POD) studies (e.g., Baxter et al. 2010, Thompson et al. 2010) that a pelagic faunal regime shift may have occurred in the San Francisco Estuary after the 1990s. This means that the constellation of mechanisms that controls delta smelt and other pelagic fish abundances might be different now from what it was in the past.

We propose that the initial management alternatives be high-outflow and low-outflow treatments with timing and triggering based on the RPA prescription of flow augmentation in September, October, and (to a lesser extent) November. Because we have observed an almost unbroken string of low-outflow Falls since 2000, it is clear that the highest-contrast, and therefore most informative Fall outflow action in 2011 would be a high-outflow action. If water-year 2011 is determined in May to be a "wet" year, then we recommend that both the relevant management alternative and the initial action to be implemented in Fall 2011 should be the 74 km "wet"-year action described in the 2008 RPA.

While a number of key variables has been historically monitored, new forms of monitoring will be required to evaluate Fall outflow effects in this plan, and both high-outflow and low-outflow management alternatives will have to be observed with the full monitoring system in place. As the adaptive management process evolves, therefore, we expect that it will be necessary to observe both high- and low-flow actions in otherwise similar years in order to scientifically resolve key management questions and achieve the first goal of this plan.

DRAFT ELEMENT: MODELS AND HYPOTHESES ABOUT SYSTEM

Conceptual models

Habitat quantity and quality model

The fall represents the time of year when delta smelt are juveniles within a few months of sexual maturity. It is a period when water temperatures are cooling down toward optimal levels for delta smelt growth and therefore, the fish may be able to make a final energetic push to acquire the calories needed to survive the winter and produce high quality eggs the following spring. The fall is also the time when freshwater flows to the estuary reach annual minima. This can restrict the region of suitable delta smelt habitat to a fairly small area (Feyrer et al. 2007; 2010).

The goal of the adaptive management experiment is to understand the major biotic and abiotic drivers of juvenile delta smelt carrying capacity during the fall to more effectively manage the species toward recovery. This goal can be simply phrased as a guiding question for the experiment: what factors affect juvenile smelt carrying capacity, or, to be more specific, vital rates during the fall?

The carrying capacity for any species is determined by a suite of factors that collectively determine habitat quantity and quality, and thus how many individuals can successfully survive to reproduce in an available habitat. Studies of stream ecosystems have tended to define carrying capacity for salmonid fishes in terms of physical habitat area (e.g., Hilderbrand 2003), while studies of large marine ecosystems have tended to define carrying capacity for fishes in terms of food web productivity (e.g., Christensen and Pauly 1998). There are few studies that have tried to explicitly quantify carrying capacities for estuarine fishes, but a mix of biotic (food web) and abiotic (physical parameters) factors have been used to define habitat suitability (Stoner et al. 2001; Manderson et al. 2002) and carrying capacity (Luo et al. 2001) for estuarine fishes along the U.S. Atlantic coast.

Like other fishes, delta smelt habitat suitability is determined by a mixture of biotic (Nobriga 2002; Bennett 2005) and abiotic (Swanson et al. 2000; Bennett et al. 2002; Feyrer et al. 2007; 2010; Nobriga et al. 2008; Kimmerer et al. 2009) factors *and their interactions* (Baskerville-Bridges et al. 2004; Hobbs et al. 2006; Mac Nally et al. 2010). For the purpose of considering a conceptual model for adaptive management, we make the following scientific arguments:

(1) If fall flows affect the carrying capacity of the estuary for delta smelt, it is not an issue of individuals being packed together too tightly in too small of a space. Rather, it is related to how space translates into opportunities for the population to meet its day to day needs in a dynamic estuary.

(2) Delta smelt are food-limited prior to and during fall (Bennett et al. 2008; and the persistent fork length decline since circa 1990 shown by Sweetnam 1999 and Bennett 2005).

   a. Based on historical food web and stomach contents data, delta smelt productivity is most efficiently supported by a diatom → calanoid copepod/mysid shrimp trophic linkage (see Moyle et al. 1992 for 1970s diet data and Kimmerer and Orsi 1996; Orsi and Mecum 1996 for diatom-zooplankton linkages).

   b. The primary factors influencing diatom, calanoid copepod and mysid shrimp productivity are three things that *will not be meaningfully influenced by fall flow experiments* - overbite clam grazing (Kimmerer et al. 1994; Orsi and Mecum 1996; Jassby et al. 2002), wastewater ammonium load (Dugdale et al. 2007), and water temperature (Kimmerer 2004).

   c. Thus, Reclamation does not expect outflow manipulation within the range that is being discussed to substantially influence low-salinity zone productivity per se.

(3) Some delta smelt will get a food web benefit from increased outflow, but it will be caused by increased opportunity to find adequate prey, not increased

low-salinity zone zooplankton productivity. Specifically, the increased Delta outflow will broaden the spatial distribution of delta smelt such that it includes more of the upper estuary. A broader spatial distribution will lead to more frequent overlap with food-producing regions like Suisun Marsh so that a greater proportion of individuals will find zooplankton densities sufficient to meet their metabolic needs.

(4) Turbidity at X2 is higher when X2 overlaps Suisun Bay than when it's in the river channels east of the Sac-SJ confluence because the estuarine currents and wind shear over the shallow Grizzly and Honker bays can continually resuspend sediment throughout the water column. Reclamation is aware this may not occur as strongly as it did historically (Schoellhamer 2011), but this is a readily testable part of the HQQ hypothesis.

   a. Higher turbidity is expected to reduce predation rates on delta smelt, but Reclamation does not at present expect to be able to observe or quantify this.
   b. Higher turbidity might lead to higher or lower histopathologic scores or other nutritional health indicators (e.g., energy density) depending on whether potential benefits of turbidity (lower energy expended finding food and evading predators) outweigh potential detriments (higher exposure to sediment-bound pesticides).

(5) A Fall outflow augmentation is the best way to meaningfully test the efficacy of improved abiotic habitat conditions during fall to positively influence the delta smelt population via both abiotic and biotic mechanisms.

A simplified but integrative conceptual model of how Fall outflow might affect the delta smelt was developed and is presented in Figure 2. This model is based on the HSG research plan, recent literature and expert opinion. All paths from Fall outflow to fish survival, health condition and fecundity involve only one negative link each; thus, all expected effects have the same sign. One possible but unlikely exception could take place if the flows are so high that the flushing of plankton overwhelms other effects.

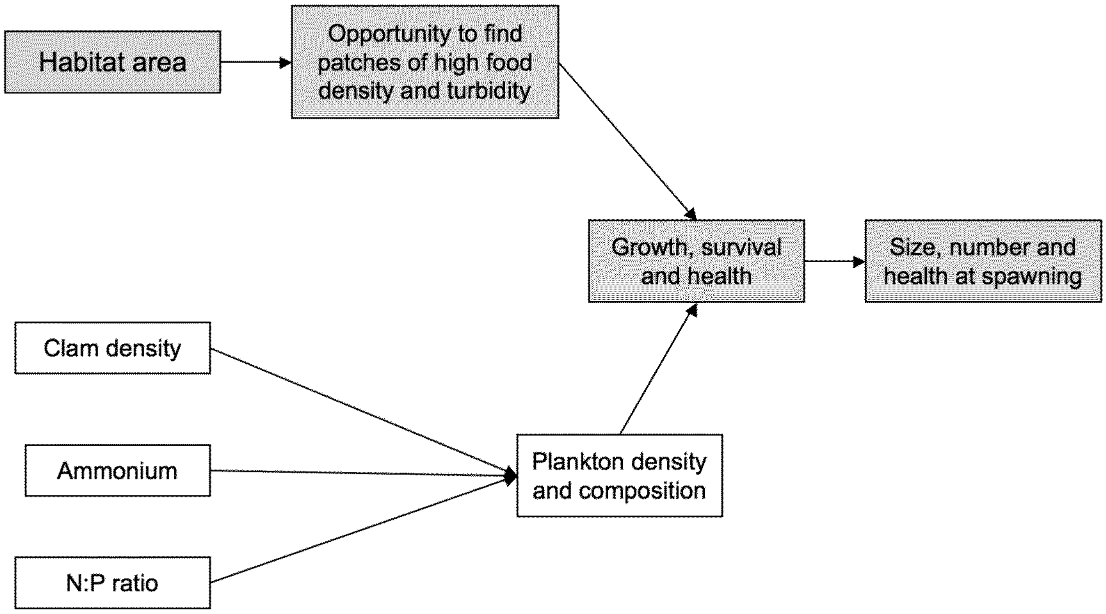

Figure 2. Conceptual model of effects (blue boxes) of Fall outflow on delta smelt through changes in habitat quantity and quality. Fall outflow affects (either directly or indirectly) the quantities on the left.

This conceptual model shows how most of the potential effects of Fall outflow are expected to occur through the processes that affect the growth and survival of juvenile and fecundity of adult delta smelt. An increase in Fall outflow is expected to increase the total area of potential habitat, mainly by incorporating the waters and wetlands at and near Suisun and Grizzly Bays. The larger habitat area incorporates much greater variation of habitat quality, which results in more abundant habitat of high quality. Greater flows will increase the transfer of freshwater zooplankton to the habitat preferred by delta smelt and will increase the transfer of particulate food and phytoplankton to the water column where delta smelt congregate.

Wastewater trophic forcing model

This model emphasizes the role of concentration of ammonia and ratios of ammonium:nitrate and nitrogen:phosphorus (N:P) in plankton production (Glibert 2010). It does not include a role of clam grazing on food density, but it revolves around the concept that wastewater-driven changes in nutrients led to the dramatic changes in productivity and composition of the food web.

According to the model, changes in flows or X2 should not strongly affect the composition of the food web, because the food web makeup is primarily determined by nutrient availabilities. Moreover, even if clam density in the available habitat could be modified by changes in X2, effects on food density would be small because production is controlled by nutrients, not grazing. Glibert suggests, therefore, that outflow augmentation on the scale contemplated by the 2008 RPA should not substantively affect delta smelt vital rates.

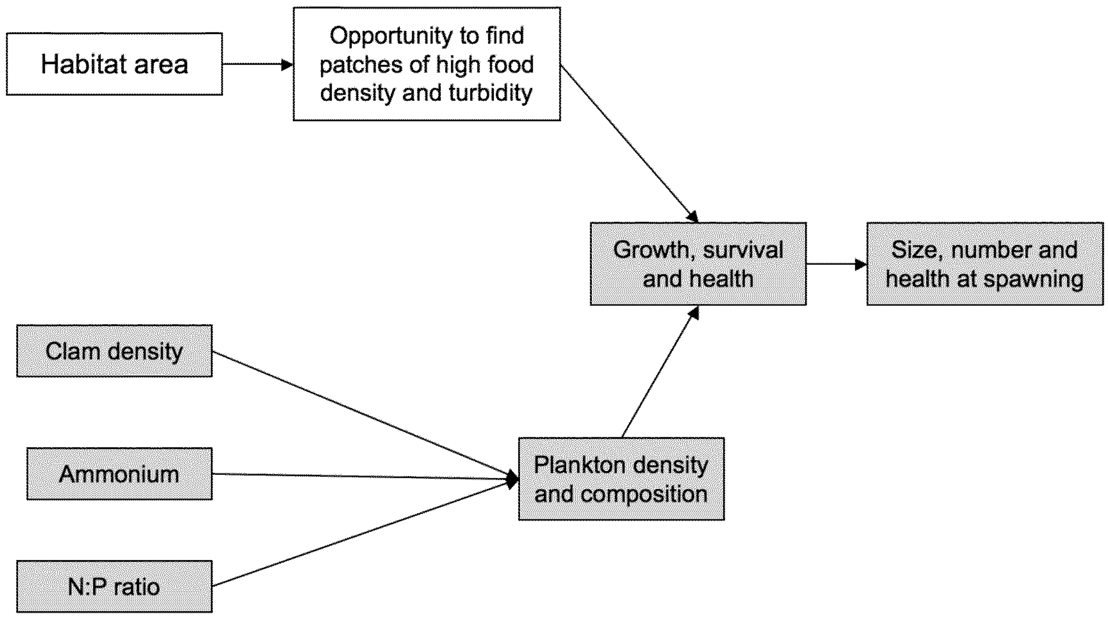

Figure 3. Alternative conceptual model (B) that emphasizes (blue boxes) the role of changes in the concentrations of nitrate, ammonia and phosphate on the food web. Contrary to the conceptual model in **Figure 2**, which is specific to the Fall, this one applies to all seasons. Fall outflow affects (either directly or indirectly) the quantities on the left.

Quantitative models

This adaptive management project relies on novel integrative analysis of existing historic data. The modeling effort in this plan is tightly integrated with the life-history modeling currently under way. Models will be used to make quantitative predictions that serve as benchmarks to assess the performance of management actions. Bayesian state-space models will be explored because they offer a great deal of flexibility and are designed to integrate data obtained from different sources and levels of temporal and spatial resolution. A detailed example of the Bayesian state-space approach applied to model the effects of Fall outflow on the delta smelt is presented below. Stakeholder input is welcomed.

Models will be used to address key questions. Note that some of these are expected to require supporting laboratory or field studies, and not just monitoring, to obtain key data.

1. What amount and quality of LSZ delta smelt habitat could be expected for what duration by varying the Fall outflow prescription?

2. What is the effect of habitat area and distribution on delta smelt distribution?

3. How does fish condition/health vary across a gradient of habitat quality?
4. How will delta smelt growth rates be affected if food density, composition, or distribution is changed during fall?
5. Does fish health/condition affect over-winter survival?
6. How does fecundity and egg quality change as a function of fish size, condition, and health?
7. What is the effect of outflow-driven changes in ammonium and N:P ratio on the composition and productivity of plankton?
8. What are the most important mechanisms linking Fall outflow to survival and fecundity?

Learning will be optimized by using the models to forecast multivariate effects of the action. The nature of the multivariate difference between predicted and observed system states will be analyzed to guide future management actions and to improve the models. Posterior distributions of state and parameter estimates can be used to optimize additional measurements to reduce uncertainty.

Variables

System state at any give time (t) and area (a) is characterized by the following variables:

1. Number of delta smelt (DS)
2. Delta smelt size (FL)
3. Abundance of zooplankton (Zoop)
4. Abundance of phytoplankton (Phy)
5. Water turbidity (Secchi)
6. Bottom salinity (Sal)
7. Water temperature (Temp)
8. NH4 concentration (Ammo)
9. P concentration (Phos)
10. Abundance of silversides (Side)
11. Abundance of striped bass (Sbass)
12. Abundance of competitors (Comp)
13. Abundance of *Corbula amurensis* (Corb)

14. Average X2 (X2)
15. Flow rate (Flow)
16. Wind speed (Wind)

Modeling approach

A Bayesian state-space approach is promising because of several characteristics of the problem. First, the system is large and heterogeneous. Its state must be described by multiple variables in many places and times. Second, the true state of the system is not directly observable, but we can observe proxies of state, uncontrolled inputs, and auxiliary variables. For example, the population of delta smelt is so low that it challenges the ability of current methods to detect it with acceptable certainty. Both the observation and the biological processes need to be modeled as outlined below. Third, bay-delta state variables are connected by a complex network of relationships that need to be taken into account in an integrated fashion, but data available come from diverse sources with different spatial and temporal resolutions. Finally, effects of unpredictable uncontrolled inputs such as precipitation, contamination events, invasions and *Microcystis* blooms are incorporated into system state and cause deviations from the goal. The fact that process noise is incorporated into system state makes adaptive management indispensable, because even if management is optimized, system state will deviate from expectations and corrections will be necessary.

According to the state-space approach, we formulate both process and observation equations. Note that the state variables defined above represent the actual state of the system and are not the same as the observations. Following the state-space approach, we consider that observed values result from sampling and measurement processes that introduce errors about the true system state.

Example process equations show process errors as "e" with the corresponding subscript (subscripts for area omitted for clarity):

$$FL_t = FL_{t-1} + f_1(Zoop_t, Secchi_t, Sal_t, DS_{t-1}, Micro_t) + e_{FL} \quad (1)$$

$$DS_t = DS_{t-1} + f_2(Zoop_t, Secchi_t, Sal_t, DS_{t-1}, Pred_t) + e_{DS} \quad (2)$$

Because we are not focusing on processes outside fall, we can model FL and DS between summer and fall or even between falls as empirical structural models with trends:

$$FL_{sep.yr} = FL_{sep.yr-1} + dFL_{sep.yr-1} + e_{FL.yr} \quad (3)$$

$$DS_{sep.yr} = DS_{sep.yr-1} + dDS_{sep.yr-1} + e_{DS.yr} \quad (4)$$

Analogous equations can be used to model between and within fall dynamics of silverside and striped bass.

$$Zoop_t = f_5(Temp_t, Phy_t, Corb_t, Comp_t) + e_Z \quad (5)$$

$$Secchi_t = f_6(Flow_t, X2_t, Wind_t, \ldots) + e_{Sec} \quad (6)$$

$Sal_t = f_7(Flow_t, X2_t, t, \ldots) + e_{Sal}$ (7)

$Phy_t = f_8(Flow_t, X2_t, Ammo_t, Phos_t, Temp_t, Corb_t, \ldots) + e_{Phy}$ (8)

$Micro_t = f_9(Ammo_t, Sal_t, Phos_t, Temp_t, \ldots) + e_{Micro}$ (9)

Temp, Wind, Ammo, Phos, Corb, Flow, and other variables can be considered observables and enter the hierarchical model in the data layer.

Observation equations are particularly important to interpret data about abundance of DS, predators, competitors, and other state variables that are likely to have large observation errors. The prefix "o" is added to variable names to indicate the result of observations, and errors are labeled "r" with the corresponding subscripts. Two equations are provided to illustrate the approach.

$oFL_t = FL_t + r_{FLt}$ (10)

$oDSt = f_{10}(DS_t, FL_t) + r_{DSt}$ (11)

Equation 11 shows that the observed numbers of fish in the samples depend both on the average abundance and on the fork length distribution, because of the effect of FL on gear efficiency (Newman 2008). Observed number of fish per unit effort could be modeled as a Poisson distribution with mean equal to the true abundance, corrected by gear efficiency, which in turn is inversely related to FL.

Each area is characterized by a surface area (A) and a total volume of water (V). Areas considered could be the same as in Newman (2008) or Feyrer et al., (2011). System state is estimated every two or four weeks between August and December. For tractability, it may be advisable to use areas and periods such that it is reasonable to assume that fish are caught in the same areas where they have spent most of the period. A spatial-temporal modeling approach may be used to account for movements among areas.

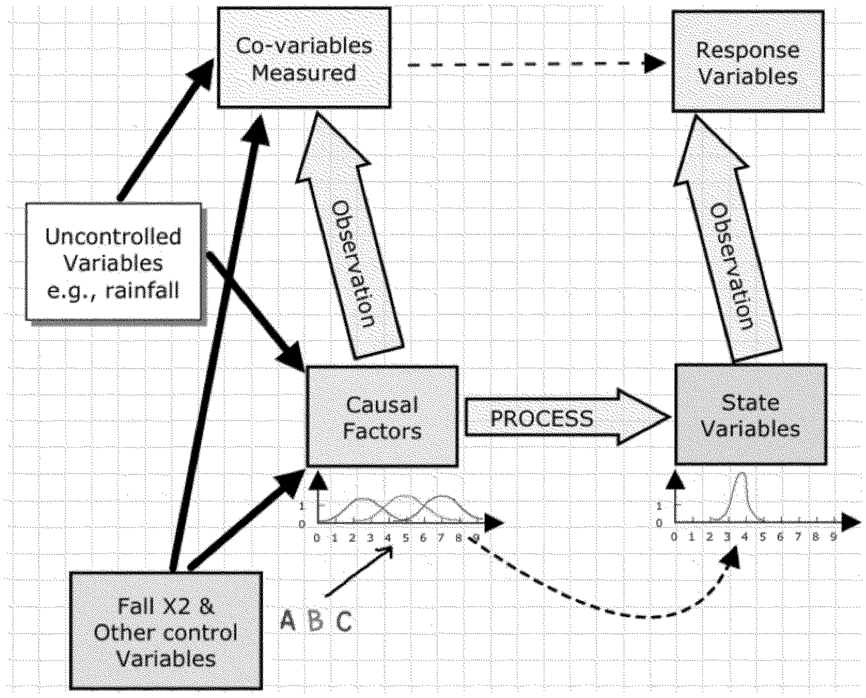

Figure 4. Relationships between system state and observed variables. Letters A, B, C represent alternative possible actions that in turn determine different probability density functions for proximate causal factors, such as zooplankton density and *Microcystis* abundance. Through ecological and physical processes, realized values of proximate factors result in a series of values for state variables such as temperature, fish abundance and size. Uncontrolled factors act in similar ways. Causal factors can only be estimated more or less indirectly through observation of covariates, and the unobservable system state can only be estimated through observation of response variables such as number of fish caught in surveys, plankton density in water samples.

Sources of uncertainty

There are four main sources of uncertainty made explicit in adaptive management: environmental, control, process and observation. Environmental uncertainty is due to the fact that there are important factors that affect the system (delta smelt) whose values are not known in advance. A management action (for instance, the 2008 RPA Fall outflow element) prescribes either outflow magnitudes or positions for X2 for specific durations. The results of applying this management depend on the sequence of water years into the future. An ex-ante prediction of action effects must incorporate the uncertainty due to not knowing what the precipitation will be in the future. Ex-post predictions remove environmental uncertainty from the model and allow identification of deviations due to other sources of uncertainty. Environmental uncertainty is incorporated into system state.

Control uncertainty refers to the fact that the controllable factors (decision variables, in this case X2) are not perfectly controllable. The actual average X2 obtained in a month may differ from the goal. This uncertainty may be difficult to assess quantitatively if it depends on rare events or complex institutional and/or legal processes. Control "errors" are incorporated into system state and propagate into the future.

Process uncertainty or error is due to the lack of complete agreement between the model and the actual biophysical process modeled. The difference between model and system state becomes part of the true state and it propagates forward with the process. Thus, process uncertainty is also incorporated into system state. Process uncertainty is a major component of our current ability to manage the system, particularly because the knowledge about the various processes has not been integrated into tools that can yield quantitative predictions. Such an integrative modeling is a key component of the present adaptive management plan.

Observation error is the difference between the actual system state and estimates based on samples. More generally, observation error results from the complex sampling, observation and measurement process that generates data. The most common source of observation error is sampling error. Observation errors are not incorporated or propagated forward in the system.

Latent variables can be useful to consider the observation error in covariates. For example, the model states that food availability affects delta smelt growth. However, the "true" availability experienced by an individual fish is not measurable and is represented by a latent variable that is related to the measureable zooplankton density.

Predictions

A key to the adaptive approach described in this document is that alternative conceptual models lead to contrasting suites of predictions at multiple levels of the ecosystem. The following table shows qualitative predictions based on both models. These provide a starting point for development of analyses that progressively discriminate the models and suggest new ones.

Table 1. Predicted effects of downstream movement of X2 in the fall based on two different conceptual models. The number of + or - symbols represents the expected relative size of the effect.

Variable	HQQ prediction	Glibert prediction
DS distribution	Broader +++	No prediction
Total habitat with food density above critical level	++	No prediction
Total habitat with turbidity above critical level	++	No prediction
DS growth in fall	+ reversal of trend	0 – continued trend
Relationship between clam and phytoplankton densities across space	No prediction	0

Relationship between $[NH_4^+]$ and phytoplankton productivity across space	-	0
DS abundance in fall	+ reversal of trend	0 – continued trend
DS growth response to density of current zooplankton composition	+	0
Rate of transfer of copepod from production to DS habitat sites	+	No prediction
Effect of nutrient corrections on proportion of *Limnoithona*	0	--

We will make quantitative predictions about the relationships once quantitative models are parameterized. The values of estimated parameters themselves will constitute hypotheses about the size and sign of effects described in Table 1.

The quantitative model that is available (Feyrer et al., 2010) predicts that when X2 is 74 km, habitat index –an integration of HQQ- will be between 5200 and 9000 with 95% confidence .

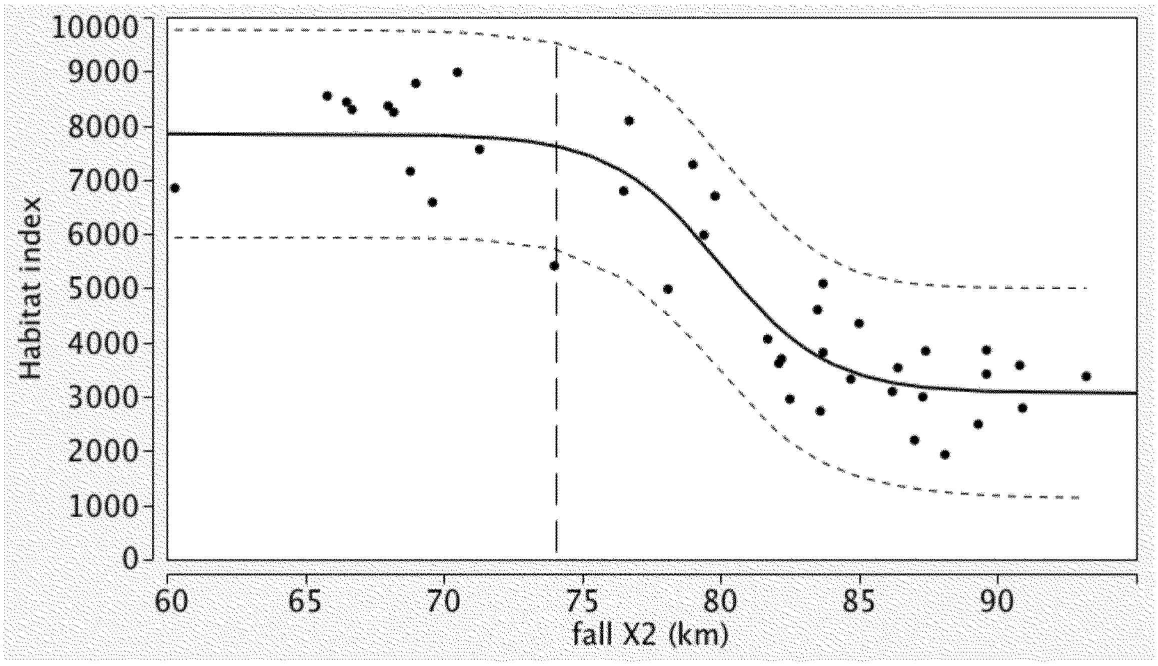

Figure 5. Relationship between fall X2 and habitat index. The shaded band is a 95% confidence interval for individual values of habitat index. The 95% CI for habitat index in one year when X2=74 km is the intersection of the vertical line and the band.

DRAFT ELEMENT: MONITORING AND STUDIES PLAN

a. Monitoring

The Interagency Ecological Program and others operate continuous sensor compliance monitoring that is a central part of the Habitat Study Group design and key to the active adaptive management strategy developed here. Thus, regular monitoring by the IEP and others must continue. This will ensure the continuity of historical time series and the ability to test hypotheses about effects of the action based on comparison of new data to historical data. Because the current abundance of delta smelt is so low, we believe some reliance on measurements of surrogate species, such as age-0 striped bass and Mississippi silversides, may be appropriate. The following data are to be collected in the Fall:

1. Temperature (continuously at several stations, plus discrete measurements once per month at the more than 100 FMWT stations as well as discrete measurements associated with other fish sampling like Chipps Island trawl, beach seine surveys, Suisun Marsh surveys, etc.)
2. Turbidity (continuously at several stations, plus discrete Secchi depth measurements once per month at the more than 100 FMWT stations as discrete measurements associated with other fish sampling like Chipps Island trawl and Suisun Marsh surveys, etc.)
3. Ammonium concentration
4. *Corbula* density (once per quarter at 13 EMP stations)
5. Specific conductance (continuously at several stations, plus discrete measurements once per month at the more than 100 FMWT stations as discrete measurements associated with other fish sampling like the Suisun Marsh survey)
6. CPUE of all non-target species collected during fisheries monitoring surveys during the fall
7. Copepod and other potential prey density (monthly at up to 22 EMP stations)
8. Chlorophyll *a* concentration (monthly at up to 22 EMP stations)
9. *Microcystis* survey (qualitative distribution assessment)

b. Laboratory Experiments

Controlled laboratory experiments can be conducted to establish and quantify causal relationships that cannot be studied in a manipulative fashion in the field. A series of experiments will quantify the effects of food density and composition on growth, condition and health of delta smelt. Then, the relationship between fish size/condition, and egg number and size will be determined. This work will be carefully integrated with current efforts to understand the genetic and environmental constraints on delta smelt reproductive strategies involving tradeoffs between number and size of clutches.

DRAFT ELEMENT: PERFORMANCE MEASUREMENT AND MANAGEMENT DECISIONS

Performance will be evaluated as the difference between observed values and qualitative and quantitative predictions established for each variable arising in the conceptual models being investigated. For the HQQ model, for example, performance will be evaluated for each of the four levels of effects in the process models, including effects of: 1) flow and X2 on physical conditions (salinity, temperature, turbidity, area of potential habitat), 2) physical conditions on zooplankton density, delta smelt survival, and transport of food from production to consumption areas, 3) food and habitat quality on growth, health, condition and survival rates, and 4) size, health and condition on fecundity and egg size or quality.

The overall performance evaluation, learning and adaptation process consists of the following steps, using the HQQ model as an example. Note that while the formulation of predictions might be relatively straightforward for variables that have long historical records, it might be difficult to make anything other than qualitative predictions about variables for which there is no monitoring history.

1. Use current data, conceptual and quantitative models to make testable hypotheses and predictions about the system. For example, based on Feyrer et al., (2010) we predict that increasing outflow to place X2 at 74 km during September and October after a wet year will cause specific increases in habitat quantity and quality and delta smelt distribution relative to otherwise similar historical years when we observed outflow equivalent to much higher X2 (say, 85 km). Improved habitat quality and quantity will lead to faster growth between August and November and lower mortality of delta smelt during the Fall when the outflow action is taken than in years when X2 was further upstream.
2. Carry out the action and monitor the results. For example, maintain X2 at 74 km during September and October. Measure delta smelt and habitat characteristics from August to January. Compare results to predictions for each variable. Use an integration tool like Table 2 for interpretation and to direct further analysis and action.
3. Interpret deviations from predicted values. This requires a deft touch, because some deviation is likely to occur even in cases where a conceptual model quite well represents the underlying processes and the quantitative models in use are good ones. In order to refine our understanding of the relationship between Fall outflow and delta smelt performance, this step might result in consideration of possible model updates and refinement of hypotheses associated with each conceptual model under consideration. As appropriate, propose a refined set of management alternatives and apply models to select one option and make predictions of its effects.

4. Compare performance of competing models or sets of models to develop an understanding of which should be emphasized because of the greater accuracy of its (or their) predictions.
5. Update monitoring and experimentation plan as a proposal according to the results of steps 3 and 4. Carry out management review and decision-making to determine whether refinements to management alternatives and associated evaluations and monitoring need to be made.
6. Implement new action and associated science elements, as appropriate. Return to step 1.

Thus, a pattern of example results as in column A of Table 2 would be interpreted as supporting the model and hypotheses. The management action would continue to be applied. Response pattern B would be interpreted to mean the models and underlying hypotheses need alteration or refinement and would lead to careful checking of the data, models, and rationales that generated the predictions. Development of new models would be strongly recommended.

Response pattern C would indicate that the mechanisms proposed are corroborated in controlled experiments, but they are not reflected in the field observations because the management action failed to change biotic and abiotic conditions for the fishes. This could be a result of the action not being sufficiently different in measurable response from the baseline ("business-as-usual") or management alternative, a weak/uncertain link between action and habitat conditions, or both. In the first case, review and adaptation may lead to a strengthening of the action, whereas in the other two situations a different action should be considered to achieve the desired changes.

Response pattern D is harder to interpret but may provide an excellent opportunity for learning. In this hypothetical example, results indicate that mechanisms linking prey density to growth to fecundity are corroborated in the lab. The action was successful in producing changes in the abiotic habitat, but that did not translate into better biotic habitat. In spite of this, the action resulted in much better growth and survivorship than predicted. This would lead to the hypothesis that there are important mechanisms linking delta smelt welfare to abiotic conditions that were not included in the model. The wealth of hypothetical explanations would be incorporated formally into the conceptual and quantitative models and tested first with the historic data and then by a new round of management action tailored specifically to coherently address both the need for information and the protection of the species.

Table 2. Decision matrix for adaptive management of fall X2. Each column is an example of possible results and subsequent interpretation and adaptation. Results of monitoring after application of a management action, and experiments are compared to predictions representing scenarios in which the management action (full RPA) is or is not applied. Each observational result can be more extreme than under no action (NA), more extreme than under action (A), similar to no action (na), similar to action (a) or in between A and NA (ana). Manipulative and observational experiments can be inconclusive (0), support (+) or oppose (-) the hypothetical model.

	Hypothetical examples of observed response pattern			
	A	B	C	D
Manipulative expt.				
Growth~prey[1]	+	-	+	+
Eggs~size[2]	+	-	+	+
Observational				
Abiotic habitat[3]	a	NA	na	a
Biotic habitat[4]	a	NA	na	na
Survivorship[5]	a	NA	na	A

[1]Effects of prey quality and density on delta smelt growth.
[2]Relationship between fish size and condition on number and size of eggs.
[3]Quantity and quality of abiotic habitat available during fall.
[4]Quantity and quality of biotic (food, competitors, predators) habitat available during fall.
[5]Proportion of delta smelt that survive until spawning.

DRAFT ELEMENT: OUTSIDE EXPERT REVIEW

Credible independent review of this plan is critical. It is also critical that there be a periodic review of the results of management and other scientific findings to support management review of the effectiveness of the conservation action and learning program. After discussion with the Delta Stewardship Council's Delta Science Program leadership, we have concluded that the most effective approach to satisfying both of these needs is to establish a permanent panel for the purpose.

As currently envisioned, the panel would convene to review Reclamation's adaptive management plan before implementation in order to ensure that it is of sufficient robustness and scientific quality to serve the intended purposes. The same panel of experts would then be retained to conduct an annual review of progress and findings and would provide a report to Reclamation and the Service detailing each panel member's findings. This report, along with other information available at the time, would be used to inform management decisions pertaining to adaptive management of Fall outflow. Discussions are currently underway to create an appropriate charge for such a review body.

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